Reliability Evaluation of 5.2GHz CMOS Receiver

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***Abstract* — A receiver's reliability evaluation in relation to its circuit block degradation is investigated with our previously proposed device degradation sub-circuit model. The receiver's performances are analyzed using both the analog parameters and digital parameters. The analog signal and digital signal degradation are monitored through two Figure of Merits parameters, SFDR and EVM, respectively. This work suggests that the hot-carrier induced LNA degradation leads to the SFDR degradation, meanwhile, causing EVM to decrease significantly. The VCO performance degradation results in minor impact on SFDR, but strong effects on the EVM.**

I. INTRODUCTION

With nano-scale MOSFETs presently reaching the maximum cut-off frequency and maximum oscillation frequency well above 100GHz [1], CMOS RF integrated circuit in mobile phone and WLAN is even more prevailing. Despite the benefit of the maturing CMOS process, CMOS device reliability always causes major concerns and casts boundaries on circuit designers.

Recently, several research efforts analyzing circuit reliability focus on RF circuit block, such as LNA [2,3], Mixer [4,5], and VCO [6]. These papers discuss on the device degradation in relation to circuit performance shift, as well as the effect of bias and operating condition strongly on circuit's degrading characteristics.

In this paper, a RF receiver's reliability based on our published sub-circuit degradation model [2] is analyzed. The reliability level of the receiver is evaluated through the introduction of two Figure of Merits parameters, one is Spur-Free Dynamic Range for analog signal monitor, and the other is Error-Vector Magnitude for monitoring the digital signal degradation. Using the proposed method, this work provides comprehensive insight for receiver reliability with respective to individual circuit.

II. DEVICE DEGRADATION MODEL

Figure 1 is previous reported sub-circuit model [2] describing device degradation. The model consists of two parts: (1) DC parameters, R_{SS} and R_{GD}, and (2) AC parameters, C_{DB} and R_{DB}. The resistor R_{SS} models degradation of drain current due to mobility reduction after device degradation, while R_{GD} models the stress induced oxide leakage current between gate and drain under normal operation. The AC parameters C_{DB} and R_{DB} model high frequency small-signal output resistance decrease for device under long time operation stress.

III. RF BUILDING BLOCKS AND RECEIVER ARCHITECTURE

Figure 2(a)(b)(c) show the circuit schematic of LNA, Mixer and VCO designed for their analysis, respectively. The cascoded LNA shown in Figure 2(a) includes inductor L_{d3} for input matching, and L_{d2} to create resonance with the total node capacitance in the drain M_2. This configuration can both increase gain at the central frequency and provide an additional band pass filtering effect.

After the LNA, RF signal is then fed into the Mixer. Figure 2(b) shows the doubly balance Gilbert Cell mixer used in our analysis. Mixer has two distinctly different inputs, the RF port and LO port. The RF port senses the signal to be downconverted and LO port senses the periodic waveform generated by local oscillator.

Figure 2(c) depicts the LC-based voltage controlled oscillator. Oscillation frequency is tuned by the capacitance varying the capacitance value of the varactor, while total transconductance must be larger enough to ensure oscillation.

Figure 3 shows the receiver architecture for reliability evaluation. A low-noise amplifier (LNA) boosts the input signal level while adding minimal the noise of the radio signal. A mixer downconverts the RF signal into Intermediate Frequency (IF) by mixing the RF signal with the Voltage-Controlled Oscillator (VCO) output signal. The central frequency of the VCO is designed at a 5.2GHz. As a result, the input RF signal is translated from 5.2GHz to IF band to meet the specification of 802.11a protocol. The design of LNA, the Mixer and the VCO are based on 0.18 μm CMOS technology. The Image-rejection filter, 90-degree shift circuit and SAW filter are simulated with ideal behavior models provided by system simulation tool.

IV. RELIABILITY EVALUATION

A. ANALOG PARAMETERS

Figure 4 shows the percentage gain degradation when different circuit blocks of the receiver is stressed at a V_{dd} level of 5V to accelerate the circuit degradation. For individual circuit block under stress conditions, we found that the LNA impacts on overall receiver gain most significantly. The gain degradation is mainly caused by the change in transconductance g_m and output resistance R_{out} at high-frequency band [2]. On the other hand, we found that degradation in VCO due to high V_{dd} stress doesn't have obvious impact on the overall gain of a receiver performance.

Figure 5 shows the degradation of linearity input-referred third-order intercept point (IIP3) of the receiver. A sharp IIP3 decrease is found when the LNA is stressed at V_{dd}=5V. The decreased IIP3 can be attributed by both the gain degradation in LNA and transconductance degradation in the current-mode Mixer [5].

Figure 6 shows the P-1dB compression point shift with the operation time. Simulation results suggest that the receiver gain is most sensitive to the hot carrier induced degradation in LNA. The linearity of a receiver can be affected by both the change in gain in LNA and transconductance in Mixer, while, the VCO has almost no impact on the overall receiver's linearity.

Figure 7 shows the percentage frequency shift of IF after direct-downconverting from RF signal at 5.2GHz. The fresh IF is designed at 5MHz. The simulation results indicates that the hot carrier induced degradation in VCO have a greater impact on the IF shift of receiver, which eventually lead to inaccurate decoding output.

B. DIGITAL PARAMETERES

Error-vector magnitude (EVM) parameter can provide a better insight into the performance of digitally modulated signals and the type of degradations present in a signal.

The procedures of obtaining EVM are illustrated in Figure 8. A reference signal, generated by digital modulation with 16QAM signal, is transmitted to the receiver (designed at Figure 3) and then downconvert to a calculated signal. After demodulation, taking the different between output calculated signal and reference signal to obtain the error-vector magnitude (EVM) values.

Figure 9 shows the increased percentage EVM against the circuit's operation time. When each of the circuit blocks is stressed at high V_{dd} level, we observe that the raised EVM comes from the VCO degradation most obviously. The LNA degradation has slight effect on EVM while the Mixer circuit under stress has virtually no impact on EVM.

The receiver's increased EVM due to VCO degradation can be explain by the increased phase noise. The phase noise level of VCO depends on its output power and Q-factor. For a VCO under operation stress, the decreased negative resistance in the cross-coupled transistors can not fully compensate the LC-inherent positive resistance, which causes the Q-factor of the VCO to degrade. Hence the energy containment in VCO's LC resonator becomes less sufficient, eventually leading to the reduction of output power [6].

V. RELIABILITY EVALUATION IN FIGURE OF MERITS

We have evaluate a receiver performances by specific analog parameters, such as IIP3, gain, P-1dB and IF shift. To evaluate the overall analog signal degradation in a receiver, Spur-Free Dynamic Range (SFDR) is introduced for further comparison.

Table 1 compares the change in SFDR and EVM of a receiver circuit after 1 year of operation when each circuit block is under high V_{dd} stress. The degradation in LNA has the most significant impact on the overall receiver's analog performance in SFDR. Mixer and VCO under stress results in almost no degradation. In the digital signals, the VCO under stress condition causes the highest percentage increase in EVM. This implies that receiver's digital is most susceptible to VCO's degradation.

VI. CONCLUSION

A receiver reliability evaluation is investigated based on a previously published degradation sub-circuit model. The overall receiver performances affected by the degradation of each circuit block are analyzed. Both the receiver's analog and digital signal degradations are investigated by two Figure of Merits parameters, SFDR and EVM. The LNA induced degradation leads to the most significant degradation in analog signal. While the digital degradation indicated by increased EVM is mainly comes from shift in VCO characteristics..

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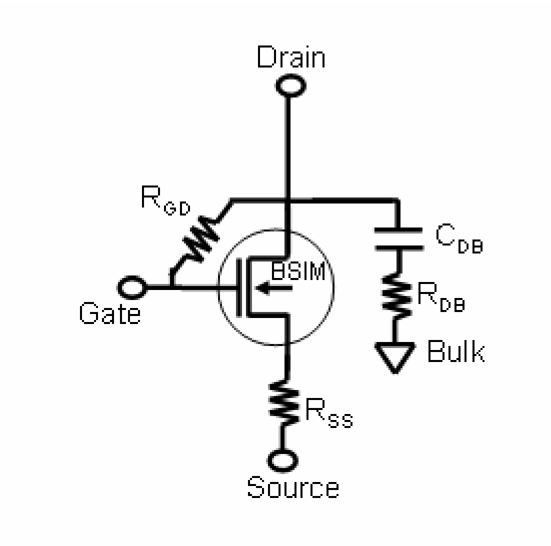

Figure 1. The sub-circuit model describing device degradation with AC parameters (C_{DB}, R_{DB}) and DC parameters (R_{SS}, R_{GD}) for device degradation modeling.

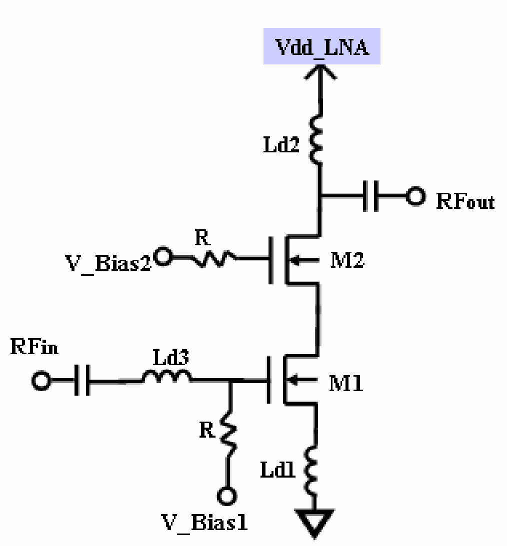

Figure 2(a). The circuit schematic of the core of LNA.

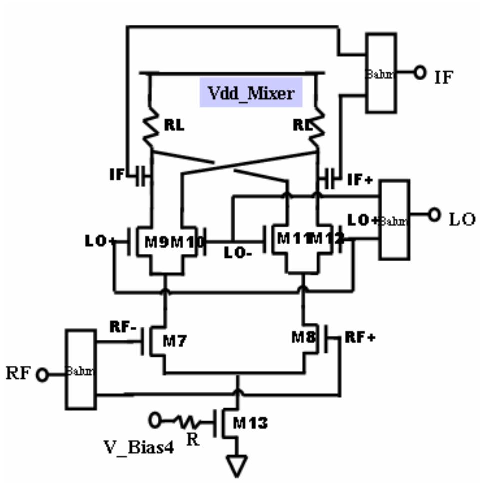

Figure 2(b). The schematic of Gilbert-Cell Mixer. The incoming RF signal is down convert to Intermediate Frequency (IF).

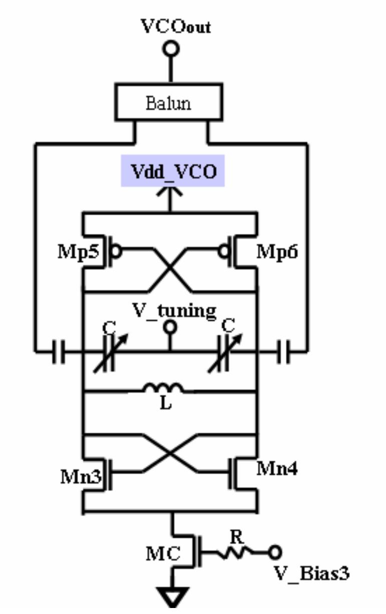

Figure 2(c). The schematic of Voltage-Controlled Oscillator.

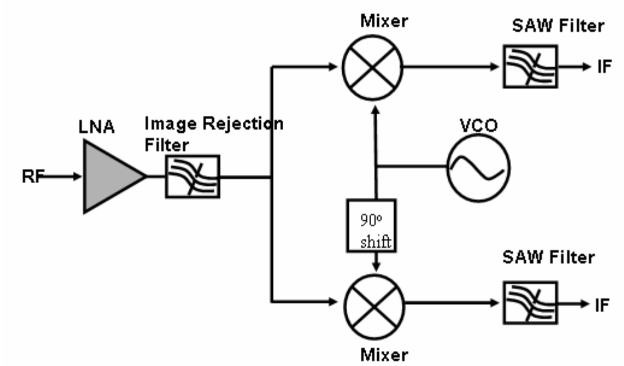

Figure 3. The system configuration of direct down-conversion receiver. The input signal boosted by a LNA is then downconverts to Intermediate Frequency (IF) by the Mixer and reference signal from the Voltage-Controlled Oscillator (VCO).

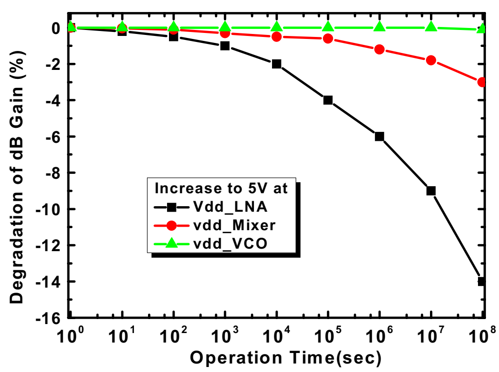

Figure 4. The percentage degradation of the overall receiver's gain with operation time.

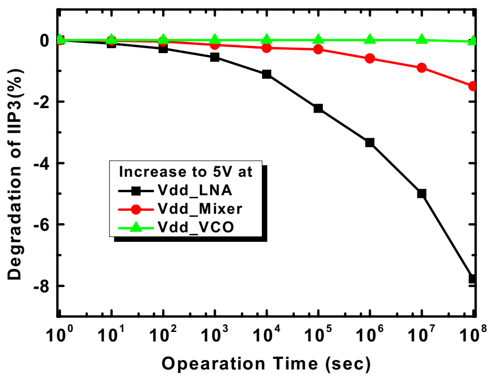

Figure 5. The degradation of the receiver's IIP3 in percentage with operation time.

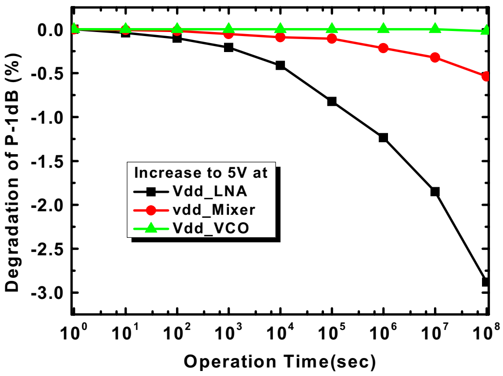

Figure 6. The degradation of receiver P-1dB in percentage with operation time. The linearity is directly related to LNA induced degradation.

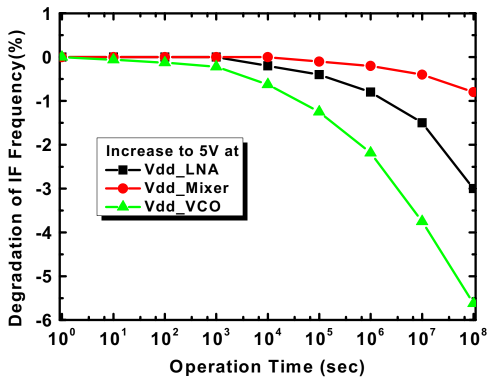

Figure 7. The percentage of Intermediate Frequency shift with operation time. The designed fresh IF is 5MHz. IF shifting will lead to inaccurate decoding.

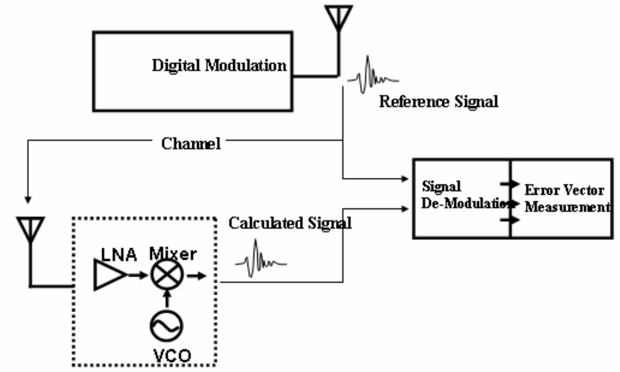

Figure 8. EVM simulation procedure. Taking the different between the calculated signal and reference signal to obtain the Error Vector Magnitude (EVM) values.

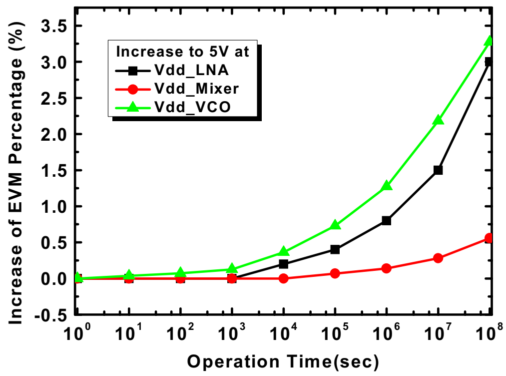

Figure 9. The increase of EVM with operation time are mainly induced by VCO degradation as a result of phase noise increase in a VCO.

Performance shift / Circuit block under degradation	Analog FoM (SFDR%)	Digital FoM (EVM%)
LNA	-7.8	2.1
Mixer	-2.1	0.4
VCO	-0.3	2.6

Table 1. Comparison of different circuit block induced receiver degradation. The LNA degradation has a greater impact on receiver's analog performance, SFDR, than on the digital performance, EVM. The VCO degradation has a larger impact on receiver's digital performance EVM, with minimal effect on a receiver analog signal shifts.